[COMMITTEE PRINT]

INVESTIGATION OF THE PREPAREDNESS PROGRAM

REPORT BY
PREPAREDNESS INVESTIGATING
SUBCOMMITTEE
OF THE
COMMITTEE ON ARMED SERVICES
UNITED STATES SENATE

UNDER THE AUTHORITY OF

S. Res. 43
(87th Cong., 1st Sess.)

ON

THE COLLAPSE OF TEXAS TOWER NO. 4

Printed for the use of the Committee on Armed Services

70708

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PREPAREDNESS INVESTIGATING SUBCOMMITTEE,
June 15, 1961.

Hon. RICHARD B. RUSSELL,
Chairman, Committee on Armed Services,
U.S. Senate.

MY DEAR MR. CHAIRMAN: At 7:25 p.m., Sunday evening, January 15, 1961, Texas tower No. 4, one of three radar platforms serving as a seaward extension of our early warning radar system and located some 80 miles at sea, off the coast of New Jersey, collapsed or toppled into 185 feet of water in the Atlantic Ocean, taking with it the lives of 14 Air Force personnel and 14 civilian construction workers who were engaged in further repair of the tower.

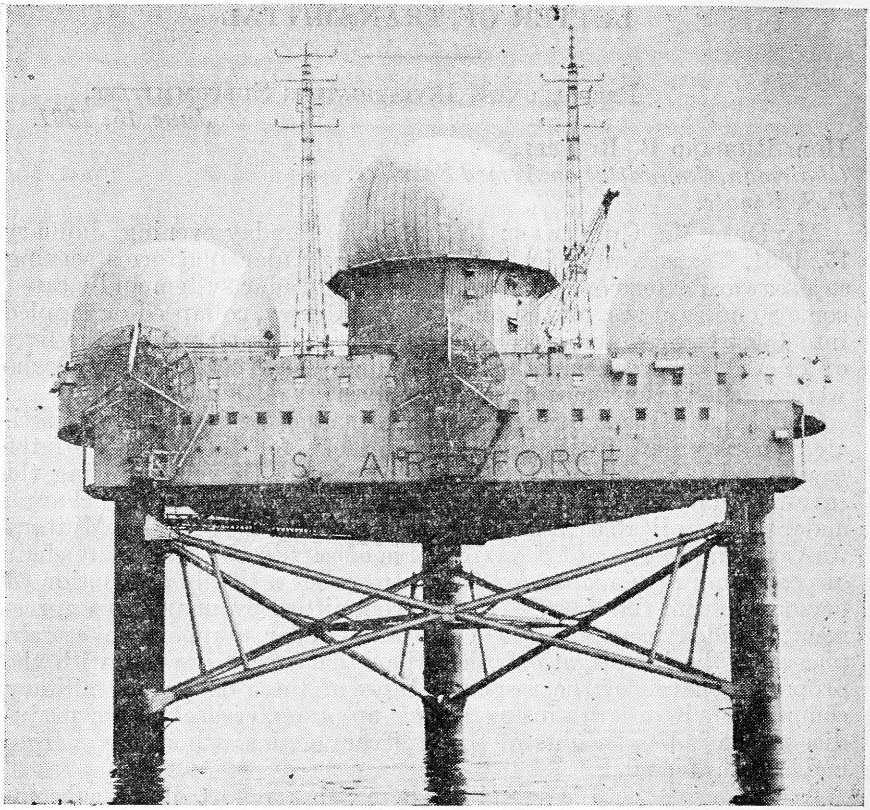
The Preparedness Investigating Subcommittee immediately initiated an inquiry into the reason or reasons for the collapse of the tower and the resulting tragic loss of lives. However, during the investigation, the Air Force announced that it was preferring charges under the applicable provisions of the Uniform Code of Military Justice against three of the Air Force officers in the immediate chain of command, presumably for failure to order a timely evacuation of personnel from the tower. The subcommittee, by unanimous agreement, decided to conduct hearings and render a report on certain phases of the investigation other than that phase dealing with the proper discharge of the responsibilities of these officers as military commanders in order to insure against any interference with or prejudice to the judicial rights of those officers against whom the charges had been preferred.

Accordingly, there is submitted herewith a report of the subcommittee dealing only with the design, construction, and repair of Texas tower No. 4, recognizing, of course, that in this form the entire circumstances surrounding the tragic collapse of the tower are incompletely reported to you for the reasons stated above. Some consideration has been given to various aspects relating to Texas towers Nos. 2 and 3, which are still standing out in the Atlantic Ocean.

The subcommittee will, however, continue to retain its jurisdiction over and keen interest in this entire matter until such time as all proceedings pertaining thereto shall have been finally concluded.

Respectfully,

JOHN STENNIS,
Chairman, Preparedness Investigating Subcommittee.



Texas tower No. 4 as it appeared prior to Hurricane Donna, September 12, 1960.

THE COLLAPSE OF TEXAS TOWER NO. 4

INTRODUCTION

By the year 1952, the necessity for radar detection of hostile aircraft at least 300 miles from their intended targets within the United States— a capability that our shore-based radars did not then possess— had become apparent to all those who had studied the problems associated with the Air Defense of the continental United States. Studies were made to determine whether there were particular regions off our shores where a cheaper and more reliable substitute for radar picket ships might be installed. Five locations were found off the northeast coast of the United States where structures, patterned after the oil-drilling rigs in the Gulf of Mexico off the coast of Texas, could be erected so as to provide proper radar coverage. They were to become known as the Texas towers. However, only three of the five were actually built, these being more specifically identified as Texas towers Nos. 2, 3, and 4.

Tower No. 4, the last one to be built, toppled into the sea in 185 feet of water at 7:25 p.m., Sunday evening, January 15, 1961, during a North Atlantic storm, taking with it the lives of 28 persons, 14 of whom were military personnel of the Air Force, the remaining 14 being civilian construction workers who were engaged in the further repair of the structure.

The day following the tragedy, the Preparedness Investigating Subcommittee announced that it would conduct an appropriate inquiry into the tragedy to determine whether or not a more formal investigation might be warranted. Similarly, and on the same day, the Department of the Air Force, through action of the commander of the Air Defense Command, established a factfinding Board of Officers to investigate the tower's collapse. Although this board was somewhat delayed in its deliberations by the illness of a material witness, it nevertheless completed its field investigation late in February and thereafter rendered its report to Air Force Headquarters.

Meanwhile, discussions had taken place between the chairman of the Preparedness Subcommittee and Air Force officials concerning the extent to which information acquired by the Board of Officers might be made available to the subcommittee in aid of its inquiry. It appeared from those discussions that the Air Force would be reluctant to reveal any of its information until such time as all Air Force proceedings concerning the tower's collapse were finally terminated. Consequently, the chairman directed the staff to conduct its own independent field investigation, which took place during the early part of March 1961.

Then, on March 20, 1961, the Department of the Air Force announced publicly that Major General Viccellio, Commander of the 26th Air Division, with headquarters in Syracuse, N.Y., had preferred charges of culpable negligence (under art. 119 of the Uniform Code of Military Justice) and dereliction of duty (art. 92) against Col. William Banks, USAF, the Acting Commander of the Boston Air Defense Sector, Stewart Air Force Base, Newburgh, N.Y., and charges of dereliction of duty against both Maj. William Sheppard, USAF, the Commander of the 4604th Support Squadron, with headquarters at Otis Air Force Base, Falmouth, Mass., and Maj. Reginald Stark, USAF, who, during a portion of the time prior to the collapse of tower No. 4, was the acting commander of that squadron. Since these officers had been given no prior opportunity to cross-examine the witnesses who appeared before the Board of Officers and whose testimony presumably gave rise to the charges against them, an investigating officer was appointed to determine which of the charges, if any, should be made the basis of possible courts-martial proceedings. During that investigation the right was extended to those charged to confront the witnesses who earlier had appeared before the Board of Officers and whose testimony was presumably damaging to those officers.

The Preparedness Subcommittee unanimously agreed that in order to avoid any interference with or prejudice to the judicial rights of those military officers, it would restrict its investigation, for the time being, to matters relating to the design, construction, and repair of Texas tower No. 4, leaving to a properly constituted judicial forum the determination of the guilt or innocence of those officers in properly discharging their responsibilities as military commanders.

The subcommittee is well aware of the fact that this self-imposed limitation will preclude it from reporting all the facts surrounding this tragic occurrence which it has accumulated in the course of its investigation. However, it was determined to be the only means by which it could be assured of assidiously avoiding an intrusion into an area where it felt that it should not trespass, at least while charges were pending.

Accordingly, the subcommittee held open hearings on May 3, 4, 10, 11, and 17, which were limited to the design, construction, and repair of Texas tower No. 4, and took testimony from the persons listed below:

LIST OF WITNESSES

Hon. Joseph V. Charyk, Under Secretary of the Air Force, accompanied by—
- Col. Robert B. Baldwin, USAF, Chief, Air Defense Division, Directorate of Operations, Headquarters, USAF.
- Col. I. H. Impson, USAF, Chief, Engineering Division, Directorate of Construction, Headquarters, USAF.
- Col. John E. Gill, USAF, Director Facilities Support, Directorate of Civil Engineering, Headquarters, Air Defense Command.
- Mr. Max Golden, General Counsel, Department of the Air Force.

Mr. E. Ross Anderson, president, Anderson-Nichols Co., Boston, Mass., accompanied by—
- Mr. John Minnich, chief structural engineer.
- Mr. Martin G. Rolland, chief mechanical engineer.

Mr. John K. Holbrook, counsel.

Capt. John J. Albers, Civil Engineer Corps, U.S. Navy, accompanied by—

Rear Adm. W. C. G. Church (CEC), USN, Assistant Chief, Bureau of Yards and Docks.

Mr. James Ayers, underwater consultant, Bureau of Yards and Docks.

Mr. Gordon Edwards, construction management engineer, Bureau of Yards and Docks.

Capt. Will J. Davis, USN, legal officer, Bureau of Yards and Docks.

Mr. L. B. DeLong, president, DeLong Corp., New York, N.Y., accompanied by—

Mr. George Bauer, vice president in charge of construction.

Mr. John L. Ingoldsby, counsel.

Mr. Bert B. Rand, associate counsel.

Comdr. Edmund R. Foster, Civil Engineer Corps, U.S. Navy.

Capt. Thomas J. White, Civil Engineer Corps, U.S. Navy.

Mr. Alan D. Crockett, general manager, Marine Contractors, Inc., Boston, Mass.

Mr. Given A. Brewer, chief engineer, Brewer Engineering Laboratories, Inc., Marion, Mass., accompanied by—

Mr. Robert Vanstone, assistant engineer to Mr. Brewer.

Mr. Eugene Rau, vice president and chief engineer, J. Rich Steers, Inc., New York, N.Y., accompanied by—

Mr. J. Rich Steers, president.

Mr. Emil V. Pilz, counsel.

Dr. Philip Rutledge of Moran, Proctor, Mueser & Rutledge, New York, N.Y., accompanied by—

Mr. Theodore Kuss, associate.

Mr. Forbes D. Shaw, counsel.

Many persons other than those who were actually subpenaed to testify, were contacted and interviewed during the course of the subcommittee's inquiry. Moreover, many documents and exhibits were received from various sources which have become a part of the official files of the subcommittee but which do not appear in the official transcript of the hearings. Such information and documentation will be incorporated into this report whenever applicable and relevant.

As the chairman pointed out in his concluding remarks on the last day of the hearing, the reluctance to mention the 28 men who lost their lives in this tragic occurrence was not because of lack of concern, interest, or appreciation for the sacrifice that they made nor because of lack of sympathy for their relatives and loved ones. So, too, in this report the recognition which they so rightly deserve is expressed at the outset by the committee, the Congress, and the country for the service and sacrifice which they made. We bow in appreciation of their service and respect to their memory as they were indeed patriots in every sense of the word. They deserve the same recognition and tribute of the country as do those persons who have similarly sacrificed their lives on the battlefields of war in preservation of our liberties and freedom and way of life.

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Having, then, restricted its inquiry to matters relating to the design, construction, and repair of the tower, the subcommittee noted the emergence of three significant issues which are enumerated below in their chronological sequence:

1. Was there a deficiency in the design of the tower?
2. Was there a deficiency in the construction of the tower?
3. Was there a deficiency in the intervening repairs which were designed to restore to the tower its intended structural integrity?

It is to these issues that this report is addressed.

SUMMARY OF FACTUAL INVESTIGATION

1. Preliminary background

The concept of the Texas towers originated from the award of an Air Force contract to the Lincoln Laboratory of the Massachusetts Institute of Technology to determine whether cheaper and more reliable substitutes might be found for the picket ships which served as a seaward extension of the early warning radar system. In a report of August 1, 1952, entitled, "Preliminary Report on the Substitution of Off-Shore Towers for Picket Vessels in the Continental Air Defense System," it was concluded that it was both feasible and practical to construct such platforms off the northeast shore of the United States at five locations out in the Atlantic Ocean that would provide proper radar coverage. More specific geographic information concerning their locations is as follows:

Tower No. 1 was to have been located on Cashes Ledge, 106 miles northeast of Salem, Mass.

Tower No. 2 was placed on Georges Bank, 174 miles southeast of Salem, Mass.

Tower No. 3 was erected on Nantucket Shoals, 113 miles southeast of Wickford, R.I.

Tower No. 4 was set in place, 80 miles east of Barnegat Inlet, N.J., but was referred to throughout as the "location off-New York," bearing 84 miles southeast of Coney Island, N.Y.

Tower No. 5 was to have been erected on Browns Bank, 75 miles south of Yarmouth, Nova Scotia.

These are more graphically depicted by the following map.

TEXAS TOWER LOCATIONS

The Lincoln Laboratory report also contained certain recommendations as to the means by which the towers should be constructed along with certain conclusions on oceanographic considerations, two of which are set forth verbatim as bearing on subsequent events.

> All authorities that have been consulted agree that the maximum storm wave in the area considered will be 40 feet high. * * * From the point of view of wave damage, there are no serious problems.[1]
>
> In design, the wave problem is twofold. The structure must be high enough to prevent wave action from reaching the flat horizontal platform and the structure, necessarily subjected to wave action, must be strong enough to avoid failure.[2]

Having preliminarily determined feasibility, the Air Force conducted negotiations and discussions with the Department of the Navy's Bureau of Yards and Docks and agreement was reached that the Bureau would act as the design and construction agency for the Air Force in the implementation of the Texas tower concept. This designation took place early in 1954.

Ultimately, the District Public Works Office of the First Naval District, with headquarters in Boston, Mass., took charge of the program and on April 9, 1954, convened a selection board to choose, from a list submitted to it, the architectural and engineering firm to conduct a more detailed feasibility study and report on the proposed offshore radar platforms. At its meeting on that date, the board decided to select for this study a firm or firms which possessed no "pet" or patented features for this type of construction on the theory that a more objective evaluation would be made as to existing designs or modifications thereof to suit the field conditions prevailing at the various sites.

While this decision eliminated from consideration at least three corporations having considerable experience in the design and construction of offshore platforms, i.e., DeLong Corp., Merritt, Chapman & Scott, and Frederick Snare Corp., these firms would, however, be permitted to bid for the construction of the towers designed by others.

The selection board[3] recommended and the then district public works officer[4] concurred, that a joint venture composed of the firms of Anderson-Nichols Co. of Boston, Mass., and Moran, Proctor, Mueser & Rutledge of New York City be selected for the feasibility study and report. A letter of intent was duly issued on June 18, 1954, and subsequently implemented by the award of BuDocks contract NOy–82761.

Conflict developed in the testimony as to the contemplated division of responsibility between the two firms in the conduct of the feasibility study and, subsequently, in the design of the towers themselves. On the one hand, Mr. E. Ross Anderson, president of Anderson-Nichols Co., testified that when it appeared that his firm was seriously being considered as the architectural and engineering firm for the Texas towers, he invited the participation of the Moran, Proctor firm in the program for what he termed the submarine foundation or footings only, the footings being that portion of the foundation structure which is embedded in the ocean floor and on which the legs of the tower rest, because of their more extensive experience and enviable reputation as designers of that type of foundation. The design of the heavy structural components, such as the legs, the braces, if any, and the platform

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[1] Preliminary report, p. 11.
[2] Ibid., p. 8.
[3] The board was composed of the following members: Comdr. J. J. Albers, Comdr. F. L. Biggs, Lieutenant LaPorte, D. Y. Taylor, with S. S. Swindells as recorder.
[4] Capt. William Wesanen (CEC), U.S. Navy.

would, in Mr. Anderson's contemplation at least, remain the responsibility of his firm. However, since the design of the footings was most directly concerned with such oceanographic considerations as ocean floor composition, soil-bearing intensities, velocities of underwater tidal currents, bottom scour, bathymetry profiles, and the like, it was agreed on June 1, 1954, that the studies of these factors would be undertaken by the Moran, Proctor firm, including the determination of probable maximum wind velocities and wave heights likely to be encountered at the various sites.

On the other hand, on July 22, 1954, then Comdr., now Capt. J. J. Albers (CEC), USN, assigned to the Moran, Proctor firm the investigation of factors leading to the design of all the heavy structural components of the five towers, including the footings, the legs, the braces, if any, and the structural frame of the platform as its responsibility under the joint venture with the Anderson-Nichols Co., the latter being relegated to the architectural layout of the interior of the platforms and engineering for the utilities systems. Captain Albers testified that the reasons for dictating this division of responsibility were—

1. That the entire structure functions as a unit through all these components and they should, therefore, be designed by one organization;
2. That the Navy wanted to utilize the experience of the Moran, Proctor firm in the designing of heavy marine structures; and
3. That this was the most feasible maner in which to expedite the work.

It is uncontroverted, however, that Moran, Proctor's participation in the project was, in fact, brought about through the invitation of Mr. Anderson; that the Navy had neither approached the Moran, Proctor firm nor solicited their participation prior to the invitation extended by Mr. Anderson; and that the Navy initially left the determination of the division of responsibility for the work up to the two firms comprising the joint venture. While the edict by the Navy, on July 22, 1954, specifying the division of work applied at the time it was made, only to the feasibility study and report, it followed through in the design and preparation of the specifications under the contract for design when awarded later to the two firms.

2. The feasibility study

On recommendation of the Moran, Proctor firm, the First Naval District awarded a contract to the Woods Hole Oceanographic Institution of Woods Hole, Mass., a nongovernmental, nonprofit research organization, for the purpose of aiding in the determination of the environmental forces of wind velocities and wave heights to which the towers would be exposed during their 20-year anticipated life and thus arrive at some criteria of forces to be incorporated into the design. The Woods Hole Institution also had the responsibility for positioning the towers and determining the water depths at the various sites. In the case of Texas tower No. 4:

(*a*) Loran type A navigation equipment, accurate to within half a mile, was used for position determination. It was found several years later through a survey conducted in October 1960 by the U.S. Coast and Geodetic Survey that the tower was actually

six-tenths of a nautical mile from where it was thought to be all that time; and

(*b*) The water depth was actually found to be 185 feet instead of the 180 feet as thought at the time of marking the spot by buoy. This error could be attributed to either the error in positioning as placing it within a deeper fathom line or because of bottom sand ripples 5 feet in height, the highest point in roughly an acre of coverage being the return received by the echo sounding equipment.

Other aspects considered in the feasibility study included the configuration, or size and shape, of the towers, which would be governed in large measure by the prevailing environment of natural forces. The aspects of configuration most immediately affected by these environmental forces were the height of the platform above mean sea level, the number and size of the legs, and braced legs as opposed to unbraced legs for a water depth of 185 feet.

(*a*) *Platform elevation.*—

> The maximum intensity of a wave force occurs close to the maximum elevation of the wave crest. If these large intensities of wave force should be applied to large areas such as the platform, excessive total forces would result. Therefore, safety and integrity of the platforms requires that the platforms themselves always be definitely above the crests of any waves.

This criterion is confirmed by the loss of two oil-drilling rigs in the Gulf of Mexico which succumbed to waves striking the platforms.[5]

The Woods Hole Institution also made a study of the weather reports for the preceding 20 years and found that the maximum wind velocity of 128 miles per hour occurred during a hurricane in 1938 and that the computed average height of the 10-percent highest waves was 66 feet which occurred during an easterly storm in November 1945. According to theory, the height of one wave in every thousand waves will be 1½ times higher than the average 10-percent highest waves. This theory has been fairly well substantiated for waves up to 20 feet in height but not for waves in excess of that height, because of the difficulty of observing and measuring waves of greater height. However, the theory is presumed to hold true for waves of greater heights than 20 feet. The measurement is from trough to crest which, as a rough rule of thumb, means that approximately 60 percent of the wave would be above and approximately 40 percent below mean sea level.

> A large and unresolved uncertainty remains concerning the maximum height of waves that may strike the platform supports during its useful life. While the maximum possible height is uncertain, there seems to be a definite probability that one such wave (gigantic) may strike the platform supports within a period of 20 years. Our design has proceeded on the basis that the occurrence of one such wave may cause stresses in the structural elements of the platform supports into the plastic range of stress for the structural materials. However, if the platform itself is not struck by such a wave, the ultimate safety of the platform and the personnel on it will not be endangered and it is believed that repairs or replacements of overstressed elements can be made if such a wave occurs.[6]
>
> After conisderable study, it was decided that the probability of 60-foot waves occurring several times during a period of 20 years at any of the locations definitely exists. * * * Such waves are associated with northeasterly or easterly storms rather than with hurricanes and the wind velocities associated with such waves are those of storms. * * * Under hurricane conditions with high wind

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[5] "Design and Construction Report on the Texas Towers Offshore Radar Platform," Moran, Proctor, Mueser & Rutledge, September 1959, p. 23.

[6] Ibid., pp. 20, 21.

velocities it is not probable that waves over 40 feet will occur. It is, however, definitely possible under these high wind conditions that the waves will be unstable and will be breaking due to wind forces and independently of bottom drag conditions.[7]

These considerations gave rise to design criteria of 125 miles per hour wind in combination with a breaking wave of 35 feet in height and this was concurred in by the scientists of the Woods Hole Oceanographic Institution.

Preliminary evaluations indicated that a height for the lowest elements of the platform above mean sea level of 67 feet was desirable. In view of all uncertainties concerning maximum waves, a single wave with a height of 90 feet seems possible in deep water. If the bottom of the platform is at elevation 67 feet, a 4.5-foot clearance for the crest of such a wave is provided. Further, * * * bottom of platform at elevation 67 provides clearance for a 96-foot wave.[8]

(*b*) *Number and size of legs.*—Minimum interference to the passage of waves led to a design configuration of a three-legged structure, the minimum number to support a platform, and to the use of legs of minimum diameter consistent with load-carrying capacity and the elimination of any auxiliary legs since "additional supporting members increase wave forces as rapidly as increased resistance is obtained."[9] A three-legged configuration for an offshore structure is rather unique in that most, if not all, the oil-drilling rigs in the Gulf of Mexico use legs in multiples of two. A three-legged structure contains no factor of safety as—

an inherent characteristic of the three-legged structure is that loss of one leg by any accidental means will result in complete and immediate loss of the platform and personnel. Therefore, accident protection in the form of increased size and strength of the main legs or supplementary legs which will not contribute to vertical support of the platform under normal conditions, but which will prevent complete loss in case of an accident is strongly recommended.[10]

The recommendation was not adopted on the ground that evacuation of the tower could take place in advance of any vessel, which might be out of control, striking the platform supports and toppling the tower.

Testimony by Mr. L. B. DeLong, president of the DeLong Corp., a pioneer in the design and construction of offshore platforms, supported the use of the three-legged structure as proper for the purpose of keeping the resistance to wave passage to the minimum consistent with load-bearing capacity.

The hydrodynamic forces of the waves were found to be of far greater significance than the aerodynamic forces of winds acting against the tower. Keeping the resistance to these forces to a minimum outweighed the safety factor inherent in the incorporation of a greater number of legs and the recommendation for the installation of auxiliary legs.

(*c*) *Braced underwater foundation.*—A water depth of 100 feet is treated as the point, generally speaking, where legs must be braced to insure integrity of support of an offshore platform. It was found in the feasibility study that—

1. The bending moments under design wave forces in cylindrical legs approximately 250 feet in length between ocean bottom and bottom of platform without bracing required unreasonably large diameter legs.

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[7] Ibid., p. 20.
[8] Ibid., p. 23.
[9] Ibid., p. 40.
[10] Ibid., p. 7.

2. Even with large diameter cylindrical legs the deflections of the platform without bracing were greatly in excess of the design criteria.[11]

It was, therefore, concluded that tower No. 4, in a water depth of 185 feet, would require braced legs.

The feasibility study and the report thereon were completed in October 1954 at a cost of $130,000 of which the Anderson-Nichols Co. received $60,000 and the Moran, Proctor firm $70,000. The feasibility report established that it was both feasible and practical to erect such offshore platforms in the Atlantic Ocean for the purpose intended.

3. Design of the Texas towers

Following the completion of the feasibility study, the district public works officer, by letter of intent dated December 7, 1954, and subsequently implemented by BuDocks contract NOy–86107, awarded a contract for the design and preparation of specifications for all five Texas towers. This, too, was awarded to the joint venture of Anderson-Nichols Co. and Moran, Proctor, Mueser & Rutledge. However, in contrast to the original contemplation of the person who invited their participation in the venture, the Moran, Proctor firm undertook the responsibility for the design of all the heavy structural components, with the Anderson-Nichols Co. relegated to the layout of living quarters, equipment rooms, and utilities systems engineering.

(*a*) *Physical description.*—In general, the towers took the form of a multidecked platform in the shape of an equilateral triangle 155 feet on a side attached to three legs, the diameters of which vary somewhat among the towers. The platform in its various decks contained equipment rooms, living quarters, the radomes, radio antennas, and heliport for the helicopters, a principal means of rapid transportation to and from the tower.

After all the equipment, such as radars, diesel generators, evaporators, and the like, had been installed on and within the platform, its gross weight was some 5,000 to 5,500 tons. Without such equipment, its structural gross weight was on the order of 4,300 tons.

The legs were lettered for identification purposes as A, B, and C in consequence of which the sides between the various legs acquired a designation of A–B plane, A–C plane, and B–C plane, respectively. In the case of tower No. 4, the B leg was the most northerly, the A leg the most southerly, and the C leg the most easterly or seaward, so that the A–B side became the side closest to the shore. The hollow A and B legs were used for the storage of fuel oil while the C leg was used as the intake for sea water from which the evaporators made fresh water. There were other fuel storage tanks installed inside the lowest deck of the platform. As installed, the A–B side of the tower was on a bearing of N. 26° E.

The following illustration is an artist's conception of a cutaway view of the platform of the tower. It was prepared by Mr. Robert McCall of Chappaqua, N.Y., through whose courtesy it is reprinted here. (Above-water X bracing, installed at time of collapse, is not shown.)

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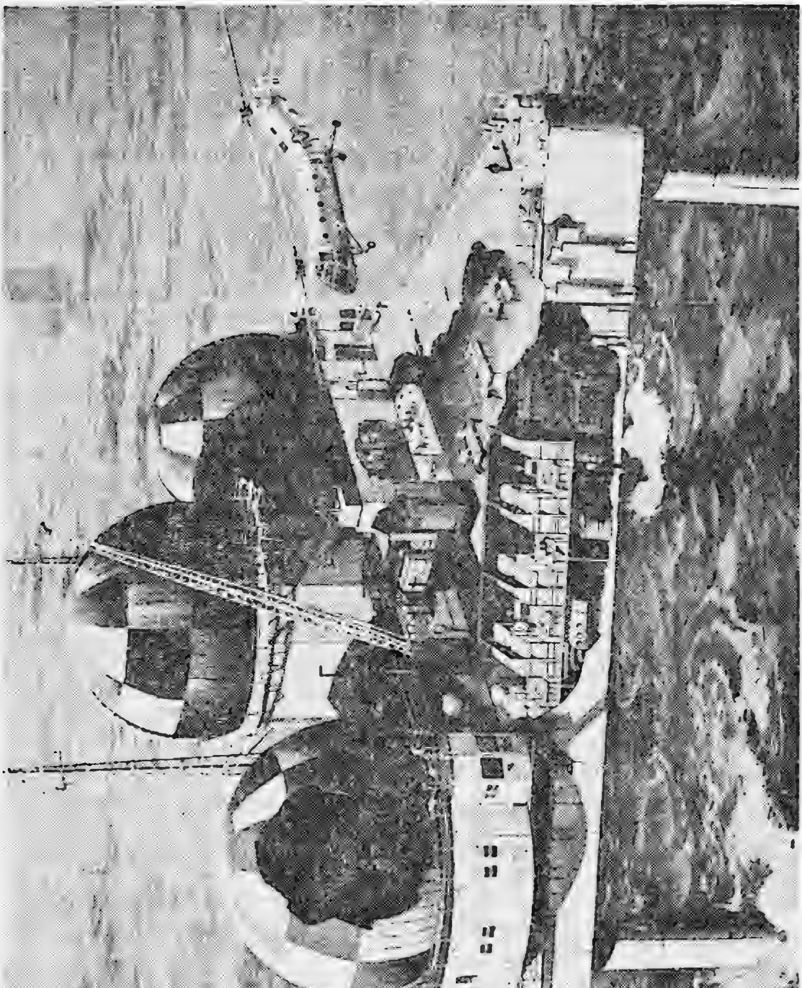
[11] Ibid., p. 57.



Cutaway view of tower platform (artist's conception).

The legs themselves, in the case of tower No. 4, consisted of an annular ring of steel $^{13}/_{16}$ inch thick with a diameter of $12\frac{1}{2}$ feet. An inner ring or core of 8 feet in diameter extended from the base of the platform to 50 feet below the surface of the water and it was between those two annular rings of steel that cement was poured to provide greater rigidity.

The pin-connected bracings of tower No. 4 were installed below water at depths of −25 feet, −75 feet, and −125 feet, the horizontal braces being affixed to the legs at those levels with the diagonal braces extending from the midpoint of each down to the legs and next lower horizontal brace.

The footings beneath each leg were 25 feet in diameter, filled with cement, and sunk or embedded into the ocean floor to a depth of 18 feet.

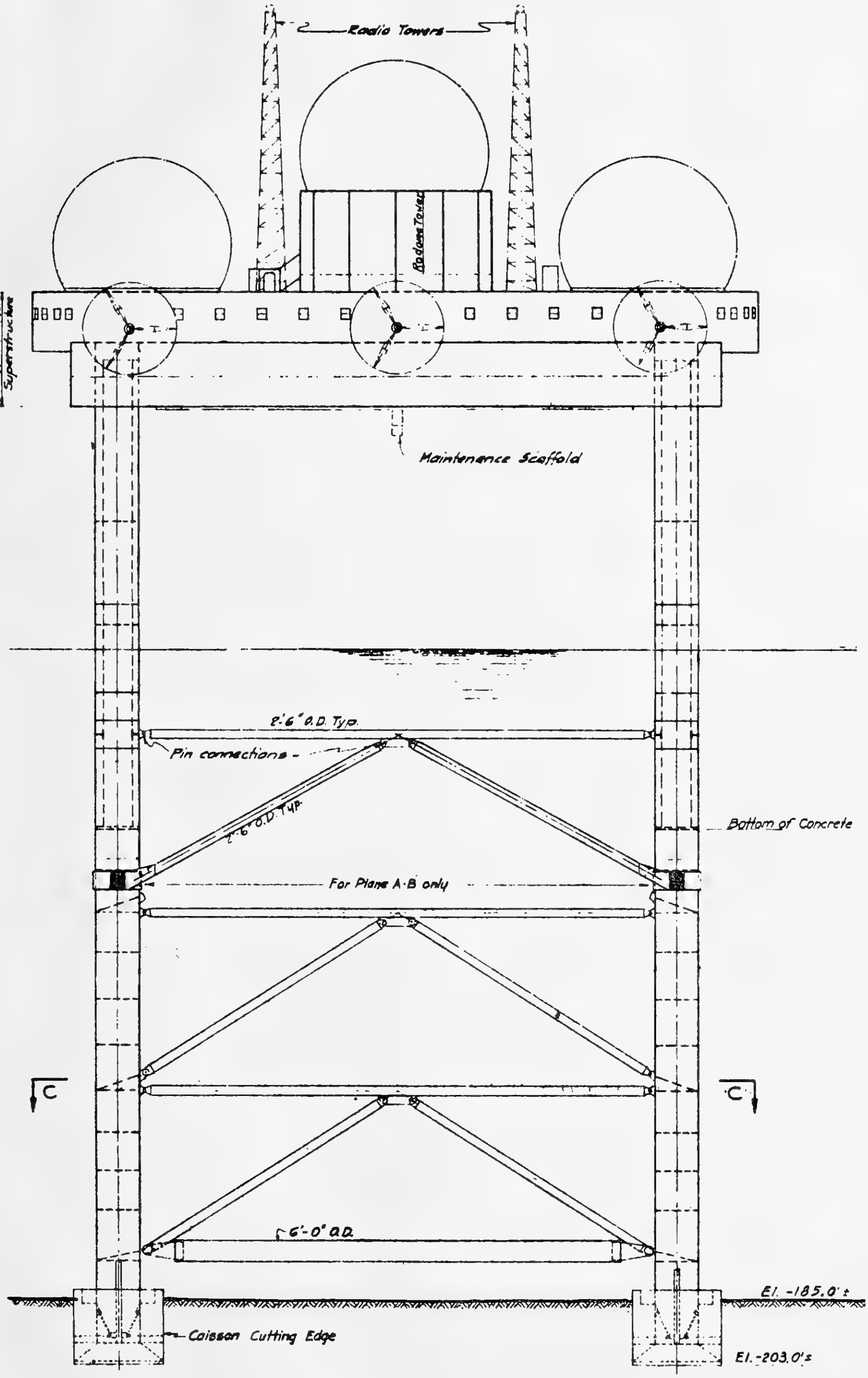
For a graphic presentation of the underwater bracing system and footings for tower No. 4, there is reprinted (on p. 13) a rough schematic diagram approximating the "as built" drawings of the tower.

(*b*) *Design specifications.*—Structural engineers use the term "static" and "dynamic" in differentiating between types of forces applied to a structure. While there is some difficulty in precisely defining the differences between the two, the term "dynamic" is generally used where the forces are instantaneously variable in either magnitude or direction, thus subjecting a structure to instantaneous fluctuations of force. Mr. Brewer, chief engineer of Brewer Engineering Laboratories, Inc., used the analogy of a diver at the end of a diving board. If he remains still, his weight will exert a static force on the board. If he jumps up and down he will impart an impulsive dynamic loading to the board by which, although there is no change in his weight, he will exert stresses on the board some three or four times his inert static-weight stress. Although the sea is in constant, unrelenting random motion, in the design of the towers, merely the static force of a single breaking wave of 35 feet in height was taken as the basis for computing the stress exerted against the tower by the sea. In a motion study conducted by Mr. Brewer on tower No. 4, at a time when the upper braces on the A–B side were admittedly not functioning, he found that a series of waves 10 to 11 feet in height caused greater stress and greater movement of the platform than did waves of 30 feet in height. This was due to the peculiar spacing between 10-foot waves, roughly the dimension of the tower, so that these waves could strike all three tower legs simultaneously. In the case of the 30-foot wave, however, its peculiar spacing was such that only one such wave would strike one leg at a time and its force would have been appreciably dissipated prior to its contacting another leg; i.e., the crest might strike one leg but by the time the wave had progressed through the dimension of the tower, its trough would strike the other leg.

No model studies for the exposure to such hydrodynamic forces were conducted, on the grounds that—

(1) It was impossible to duplicate the random nature of the sea waves in an artificial basin; and

(2) The design engineers were told that a Reynold's number, by which the miniature model is magnified through mathematical multiplication to the actual size of the tower itself, would not be applicable in this case.



ELEVATION A-A

Scale: 1" = 20'

Diagram of underwater bracing system.

The K-type brace with pin connections, as opposed to welded connections, was incorporated into the design for the underwater bracing system on tower No. 4 on the ground that the pin connection would eliminate secondary bending stresses because of its lesser rigidity. In the original design, the clearance or tolerance between the 8-inch diameter of the pin and the hole into which it was to be inserted called for $\frac{1}{64}$ inch.

All the towers were designed to withstand the forces of a 125-mile per hour wind coupled with a breaking wave of 35 feet in height.

Shortly after the award of the contract for the design and specifications of the Texas towers to the Moran, Proctor firm, the services of a Mr. Theodore Kuss were engaged as an employee of that firm. Mr. Kuss was the inventor of a method of erecting offshort structures in deep water. His patent provided, in essence, that the template, consisting of the legs and their braces, would be completely fabricated in a shipyard, towed to the site in a horizontal attitude, and, through the flooding of buoyancy chambers, upended or tipped up to a vertical position.

Up until the time of his employment with the Moran, Proctor firm, the patented Kuss method of erecting towers had not been considered by the Navy's Bureau of Yards and Docks as a process to be utilized in erecting tower No. 4. This method had never actually been used before its adaptation for tower No. 4 and has reportedly been used but once since then. In the Kuss patent it is stated:

> Another object of the invention is the provision of a structure of such a shape that it may be built economically and still have the required strength to resist stresses due to floating the same on water and those due to erection of the structure underwater.[12]

The patent also contains a statement to the effect that a sudden swinging about the horizontal axis of the template might set up undesirable stresses in the caisson and create dangerous conditions.[13]

In the actual process of tipping up the tower No. 4 template, it rotated, through unequal flooding of the buoyancy chambers, 17° in one direction, then 34° in the opposite direction about the horizontal axis before being brought under control. The design of the template did not include, per se, the stresses that might be exerted on the structure during the towing and tipping up operations.

For illustration of the Kuss tip-up process there is reproduced (on p. 15) a schematic sketch of Texas tower No. 4 erection procedures.

In the case of tower No. 4:

> The design contemplated that the separate foundation structure would be provided with a temporary construction platform which was limited in weight to 375 tons by the flotation and upending requirements of the horizontally constructed foundation structure. The design planned that the temporary construction platform would be used for the operations of securing the foundation structure to the ocean bottom by means of steel pipe piles driven through skirts at the bottoms of the foundation legs and for concrete filling of the bottom portions of the foundation structure and the placing of concrete linings in the upper portions of the foundation legs.[14]

Then the permanent platform would be floated into position between the legs after their embedment and strengthening through concrete lining.

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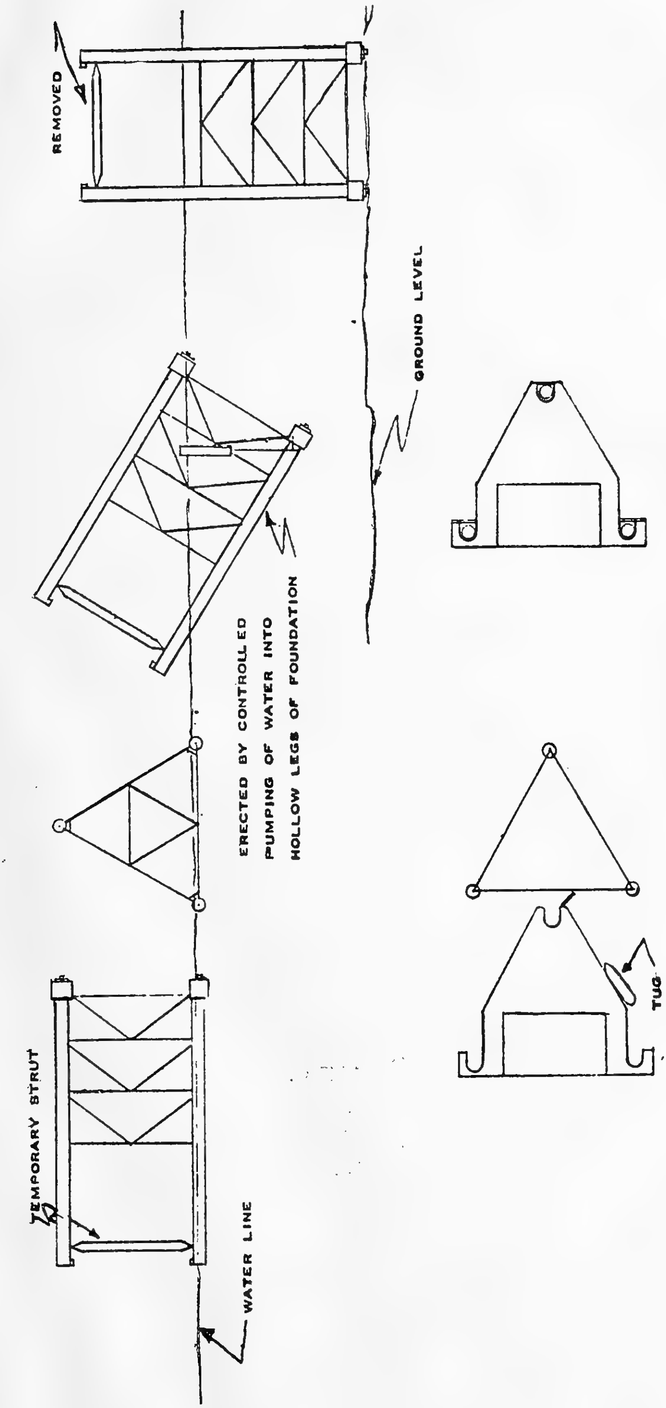
[12] Patent No. 2,586,966, dated Feb. 26, 1952, entitled "Deep Water Oil Well Drilling System." Col. 1.

[13] Ibid.

[14] "Design and Construction Report," p. 60.



SKETCH #1

TEXAS TOWER 4
ERECTION PROCEDURE

The contract price for the design and specifications of the five towers amounted to $600,000, of which the Moran, Proctor firm was to receive $450,000 and the Anderson-Nichols Co. $150,000. Contract administration costs and change orders increased the total cost to $953,000.

4. Construction of the Texas towers

By letter dated December 29, 1954, the district public works officer of the First Naval District requested an acceleration of the design of Texas tower No. 2 on Georges Bank. The shipyard construction of tower No. 2 proceeded almost simultaneously with the design in that there was only a 1-month leadtime between design and actual fabrication of the elements of the structure. Tower No. 2 was constructed under a cost-plus-fixed-fee BuDocks contract NOy–88201 by the DeLong Corp. in a joint venture with Raymond Concrete Pile Co. and was completed in November 1955.

The initial design for tower No. 2 called for the installation of I-bar link bracing. DeLong objected to the bracing on the ground that from his experience as a pioneer in this field, he knew that it could be built differently by eliminating the bracing and increasing the depth of the embedment of caissons and the design engineers permitted this to be done.

The DeLong method of constructing tower No. 2 consisted of the platform being first supported by auxiliary legs from which the permanent legs were lowered, embedded, and stiffened before the weight of the platform was transferred to the permanent legs. The construction of tower No. 2 in the use of the DeLong method proceeded without incident. It is located in 56 feet of water, possesses legs of 10 feet in diameter with a 15-foot diameter for embedment purposes which extends to a depth of 48 to 50 feet below the ocean floor to 15 feet above for abrasion protection. Its platform is at an elevation of 61 feet above mean sea level.

On November 20, 1955, tower No. 2 was subjected to a severe storm with sustained winds from the northeast of 75 miles per hour and waves of 45 to 50 feet in height. Breaking waves from opposing seas caused by tidal currents or shifting winds in a clapotis effect threw water against the bottom of the platform four times during the course of the storm. The "flying bridge" or rotating maintenance platform suspended 14 feet below the tower platform suffered some damage from wave action. However, there was no structural damage to the tower itself. There was no increase in design criteria for the remaining two towers resulting from the knowledge and experience gained from this storm at tower No. 2.

Invitations to bid for the construction of towers Nos. 1, 3, 4, and 5 were issued by the district public works officer on July 5, 1955. During the bidding period, tower No. 5 was eliminated because of fund limitations. Under the bidding procedure, the prospective builders were permitted to bid on each tower separately and on any combination of the towers. The DeLong-Raymond joint venture was the low bidder on all the towers individually except tower No. 4 and all combinations of towers except combinations where tower No. 4 was involved. Accordingly, it was the recommendation of Captain Albers that the DeLong-Raymond joint venture be awarded the contract for the construction of towers Nos. 1 and 3 and that the J. Rich

Steers-Morrison-Knudsen joint venture be awarded the contract for the construction of tower No. 4. Dr. Charyk, Under Secretary of the Air Force, testified that fund limitations required the elimination of tower No. 1, which had the effect, as well, of eliminating the DeLong Corp. which had directed the successful construction of the first of the towers from any further participation in the construction of any of the remaining Texas towers.

Mr. DeLong testified that his corporation, through his chief engineer, Mr. Suderow, since deceased, had an agreement with the design engineers that if his corporation were the low bidder on tower No. 4, it would be permitted to construct it in accordance with a method proposed by DeLong and similar to the method shown as scheme B on figure 48 of the Design and Construction Report. This was emphatically denied by both Captain Albers and the design engineers. However, as proof of his contention, Mr. DeLong testified that if he were to be required to build a pin-connected tower under the horizontal tow and vertical tip-up of the Kuss method he would not have submitted a bid and, in fact, "did not want any part of it." Substantiation of his testimony that there was an implied or tacit agreement with the design engineers took the form of documentation furnished pursuant to a subpena duces tecum served on Mr. DeLong requiring him to furnish all plans, drawings, proposals, submissions, contracts, and agreements prepared or made by the DeLong Corp. in connection with, in contemplation of, or in the solicitation of bids for, the construction of Texas towers Nos. 1, 3, and 4. The documents produced included the instructions by the DeLong Corp. to its possible subcontractors in preparing their bids, a memorandum of agreement and joint venture agreement with Raymond Concrete Pile Co. for the disposition of barges proposed for use in construction of tower No. 4, and a drawing dated October 17, 1955, similar to scheme B. The DeLong plan essentially called for welded connections for the braces, and a vertical tow of the template to the site. His objections to the use of pin connections stemmed from the fact that "the sea never gets tired," its constant random motion would only serve to cause wear of the pin connections; and secondly, that there would be no means by which to evaluate the stresses imposed on the template during a horizontal tow to site and tip-up, along with a danger that one or two legs might touch bottom first, resulting in even greater stress. He also objected to the time during which the tower would be at the mercy of the sea in floating the permanent platform into position between the three legs after they were upright.

On the other hand, there was introduced into the record a memorandum which Dr. Rutledge, of the design engineering firm, prepared of a conference with Capt. Garner Clark, USN, Assistant Chief of the Bureau of Yards and Docks, at which Captain Clark stated that he had denied DeLong permission to submit a bid based on an alternate design for the construction of Texas tower No. 4. Moreover, Dr. Rutledge testified that the design engineers had no authority to make any agreement such as Mr. DeLong alleged, nor did they do so.

Whether, in fact, there was or was not an agreement to construct tower No. 4 by an alternate design and alternate method of erection is not, in and of itself, of any great significance. However, the reasons for seeking such an agreement are important. There was interposed

such a serious objection to the use of pin-connected braces and the Kuss tip-up method that a pioneer in the field "wanted no part of it." So, too, Mr. Anderson, when asked whether he would have used pin connections if he were designing the tower, testified: "I would question very much that we would."

The J. Rich Steers, Inc.-Morrison-Knudsen bid for tower No. 4 was almost identical to its bid for tower No. 3 even though it was to be erected in far deeper water, would require a great deal of extra work in fabrication and installation of the bracing, and, generally, was a far more ambitious undertaking. Mr. Rau, vice president and chief engineer of J. Rich Steers, Inc., testified that his corporation had had a great deal of experience in marine construction but lacked experience in the use of jacks and jacking assemblies for elevating the platforms upon the legs. Mr. Rau stated:

> Therefore we associated ourselves with Morrison-Knudsen in September of 1955 because they had with them a man named Lucas, who was a former partner of DeLong's for a number of years, and had experience, a number of experiences, in jacking up the platforms.

Mr. Lucas was then under a prohibition by agreement with the DeLong Corp. not to compete or assist anyone to compete in the type of enterprise in which the DeLong Corp. was engaged. The DeLong Corp. brought suit against Lucas and was awarded damages of $647,000 plus interest for breach of the agreement as constituting the proximate cause of the loss of the contracts by DeLong for the construction of Texas towers Nos. 3 and 4.[15]

A lump sum contract NOy–88202 for $16,431,000 was awarded to J. Rich Steers, Inc.-Morrison-Knudsen as a joint venture for the construction of towers Nos. 3 and 4 in November 1955.

J. Rich Steers, Inc. (hereinafter abbreviated as Steers) owned the greater percentage of the joint venture and assumed construction management and responsibility for the project with Morrison-Knudsen furnishing primarily support personnel. Steers first tried to subcontract the fabrication to Bethlehem Steel but their workload would not permit it. Consequently, Continental Copper & Steel Industries, Inc., received the subcontract for fabrication from Steers and leased the South Portland, Maine, basin for the prefabrication work.

The construction of Texas tower No. 3 proceeded by utilizing temporary legs to bear the weight of the platform until the permanent legs were lowered, embedded, and stiffened. It was placed on Nantucket Shoals in 82 feet of water. Its legs have a constant diameter of 14 feet and are embedded into the ocean floor to a depth of 60 feet. Its construction appears to have progressed without incident except that one permanent leg became tilted in being lowered to the ocean bottom and this was not corrected. Tower No. 3 was completed late in 1956.

During fabrication of Texas tower No. 4, Steers requested several change orders which deviated from the original design and these were approved by the design engineers and the Navy's Bureau of Yards and Docks, the latter also having previously approved the design specifications. These changes had several major consequences:

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[15] *DeLong Corporation* v. *Lucas* (1959), 176 Fed. Supp. 104 affirmed on appeal (1960), 278 F. 2d 804.

(*a*) In permitting the substitution of a permanent platform for the originally contemplated temporary one, it meant that the permanent platform would be jacked up above the water before the legs had been embedded into the ocean floor and before any concrete stiffening had been placed in the legs.

(*b*) Without the legs first being embedded, there was insufficient draft (water depth) above the upper panels of bracing to float the platform into position between them. For this reason, the upper panels of bracing had to be folded down in the initial stages of construction to be connected up later underwater.

(*c*) In order to fold down the upper panel of bracings, an increase in the tolerance between the size of the pin and the holes into which they were to be inserted was granted. Difficulty in fabrication had required an increase in tolerance from the $1/64$ inch called for in the design to $1/16$ inch. For the upper panels of bracing this was further increased to $1/8$ inch.

The design engineers had first approved, then later disapproved, the method proposed by Steers for lashing down the diagonal struts during the tow to site and transmitted to Steers certain required modifications. It is inferred from the testimony of Mr. Rau that the modifications required by the design engineers reduced the strength of the lashings from that inherent in the Steers' proposal.

The template (consisting of the three legs and their permanent and temporary bracings) and, in a separate element, the permanent platform, were towed to sea from Portland Harbor on June 28, 1957. The template was floated in a horizontal position resting on the A–B plane in accordance with the Kuss patent.

Mr. Kuss had granted a royalty-free license to his employers, Moran, Proctor, Mueser & Rutledge, who, in turn, granted an identical license to the U.S. Government for the construction of tower No. 4.

A storm, which did not exceed the criteria for the towing operation, occurred at the site which delayed the tip-up process. It was discovered that the two diagonals in the upper panel of braces on the A–B side had broken loose from their lashings and were damaged. During the tip-up process these diagonals sheared off their connecting pin plates and were lost.

The Navy's officer in charge of construction, Comdr. Edmund Foster (CEC), USN, the designers, and the contractor held various discussions over the action which should be taken in view of the structural mishap which had occurred. The two alternatives were to return the template to port to effect repairs or to attempt repairs at sea. Commander Foster declined to assume responsibility for the decision. Conversely, the contractor denied making the decision and testified that the responsibility had to rest with the Navy. The design engineers disclaimed any responsibility for the decision. All the parties concerned, however, agreed that the other party's decision in attempting repairs at sea was correct.

The platform was towed into position between the three legs (now in a vertical position) and sea swells of about 3 feet in height caused it to dent the three legs, the indentations being an average of 10 feet high, 6 to 8 feet wide, and about 10 to 12 inches deep. The plating of the legs exposed to the crushing action of the platform framework was $13/16$ inch thick which was too thin, without being

supported by the concrete stiffening, to resist the force. It was agreed that the contractor's operations were carried out in accordance with the erection procedure contemplated by the plans and specifications. It appears that adequate provision was not made to stiffen the steel shells of the tower legs in the critical region. On July 12, 1957, the Bureau of Yards and Docks agreed to finance the direct costs of strengthening the legs at their indentations which ultimately would end up about 10 feet underwater after embedment of the footings.

The heavy permanent platform was jacked up on the three legs prior to any concrete stiffening being placed in the legs, being jacked up clear of the water on July 8, 1957.

The water depth, as noted previously, turned out to be 185 feet instead of 180 feet as originally contemplated in the design. Also, the total range of tide was measured at 3½ feet instead of the original estimate of 1 foot. Thus, in order to achieve a safe clearance of the platform above mean sea level, it was necessary to modify the design by—

(*a*) Reducing the embedment of the footings from 20 feet to 18 feet; and

(*b*) Raising the platform to the maximum extent permitted by the design.

These resulted in achieving a platform elevation of 66.5 feet instead of the 67 feet called for in the design.

5. Repairs to Texas tower No. 4

Agreement apparently having been reached to attempt repairs of the tower at sea, the design engineers, under contract with the builder, designed a collar connection encircling legs A and B as a means by which to secure the replacement diagonals to the legs. Dardelet bolts having a serrated shank were inserted through the collars into the legs to keep the collars from moving vertically on the legs. The installation of these bolts required underwater cutting and fitting to close tolerances and the repair was only as good as the capability and integrity of the divers working under adverse conditions at an underwater depth of 65 feet. Moreover, the repair was made even more difficult by the reactions of the legs to the forces of the sea in that, even at this time, the tower's foundation was in motion. These repairs were completed by November 1957 and the tower was accepted by the Navy from the contractor. The Navy did not conduct an underwater inspection prior to turning the tower over to the Air Force. In the motion picture film of the construction of tower No. 4, which was shown during the hearings, a ball, suspended so as to move freely, was in rather violent motion at the time of Air Force acceptance.

By the summer of 1958, the Air Force personnel operating the tower had complained of sensations of considerable movement of the platform with frequencies of 15 to 18 cycles per minute. Although those who observed the motion had no means of properly measuring its extent, such motions did not occur during severe weather conditions as the maximum wind velocity and wave height during that period were about 30 knots and 15 feet, respectively. However, the frequency of the horizontal oscillations gave some clue as to the stiffness of the tower (design frequency was 37 to 46 c.p.m.) and the design engineers

made a special analysis to determine whether or not the replaced diagonals on the A–B side were functioning. This analysis led to the conclusion that the upper tier of bracing on the A–B side was not functioning and this, in turn, prompted an analysis of the strength of the tower under this condition and the amplitude of motion which might indicate danger. It was estimated that, if the tower leg steel were stressed to the yield point, the tower could stand a 125 mile per hour wind combined with a 36 foot high wave or an 87 mile per hour wind combined with a 67 foot wave. The horizontal deflection at the same time would be about 6 inches. Because of this motion and the fact that the tower had not yet experienced a hurricane, the tower was totally evacuated of personnel in advance of Hurricane Daisy in August of 1958.

The Brewer Engineering Laboratories, Inc., of Marion, Mass. received a subcontract from Hallicrafters Co. to conduct a motion study of the tower during the fall of 1958 and winter of 1959. The Brewer study had as its purpose—

(*a*) To experimentally measure the translational (horizontal) and rotational (twisting) excursions and corresponding frequencies (the number of times per minute it did each) of the tower platform from aerodynamic and hydrodynamic forces;

(*b*) To measure the caisson bending stresses at the lower deck; and

(*c*) To investigate the integrity of the subsea truss work (the functioning of the underwater braces).

Prior to undertaking the experiment, two conferences were held:

(*a*) At the Air Force Cambridge Research Center in Bedford, Mass., where it was revealed that the Air Force was interested in rotational motions and frequencies of the platform because of these influences on radar search equipment; and

(*b*) At the offices of Moran, Proctor, Mueser & Rutledge, who were interested in caisson bending at the lower deck and knowledge as to the integrity of the upper tier of bracing in the A–B plane.

At both of these conferences the integrity of portions of the underwater truss work was questioned. It was revealed at that time that—

> the 8-inch I.D clevis holes were bored one-eighth inch oversize to facilitate assembly. Moreover, two clevis brackets were broken off in tower transit to the installation site. A repair at sea was attempted by replacing the broken brackets with eared collars. These collars attempted to anchor the lower end of the diagonals in the upper frame of the A–B plane to caissons A and B, respectively. Considerable doubt was expressed regarding the success of this repair.[16]

Mr. Brewer asserted that Mr. Kuss had told him that all he (Kuss) required was a measurement from Brewer of the natural frequency of the tower and Kuss could then compute all other facets of the tower's functioning.

The matter of the final tolerances authorized on the clevis joints was also unclear. In the meeting of November 12, 1958, Mr. Kuss indicated that tower motions of plus or minus 2 inches could occur without taking up known clearances of the pins in the first truss bay beneath the ocean surface. Commander Foster also stated that his

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[16] Brewer Engineering Laboratories Report No. 173, pp. 5, 6.

office in Bath, Maine, had found it necessary to approve an increase in tolerance in certain instances greater than those initially called for in the Moran-Proctor structural drawings because of difficulties encountered in fabricating the template.

During the winter of 1958–59, winds to 65 knots and waves to 30 feet were experienced over a 5-month survey. From the Brewer study it was found:

(*a*) That the observed natural tower frequencies (17 to 23 c.p.m. translational and 23 to 24 c.p.m. rotational) were approximately one-third of those predicted by the designer's theoretical calculations.

(*b*) That the subsea truss work was essentially ineffective for excursions up to 3 inches and rotations to 0.1°. It was expected that the clearances in the pin connections would be taken up with increasing deflections of the tower platform.

(*c*) That positive evidence of the fact that relative motion between members of the underwater truss system occurred during the ever-present tower oscillations, was provided by hydrophones. The metallic rumbling noises heard beneath the tower were coincident with the frequency of tower motion. They were interpreted to result from the movement of very heavy metal objects.

(*d*) That 10-foot waves produced the greatest tower motions and therefore stresses over the range of waves 0 to 30 feet in height experienced during the study.

(*e*) That hydrodynamic forces (waves) were by far the more important over aerodynamic forces (wind).

It was recommended by Mr. Brewer that, if the extent of the platform excursions and rotations were objectionable, then an investigation should be conducted to determine whether greater rigidity might be achieved by installing bracing above water to reduce the bending moments of the legs. This suggestion was limited to a means by which to reduce platform motion and was not intended as a means of strengthening the tower. Mr. Brewer testified that a complete stress reanalysis would have to be made because such bracing would increase the resistance to wave passage and, therefore, could conceivably have the effect of actually weakening the tower.

From merely a cursory computation which was not required as a portion of his responsibility under his contract, Mr. Brewer found that if the tower legs were to have no bracing, the weight of the platform alone would collapse the legs without any wind or wave force being exerted against the tower.

The design engineers, however, found fault with the Brewer study by the following comment:

> During the fall of 1958, a subcontract was given to the Brewer Engineering Laboratories, Inc., to perform motion studies on the tower. These consisted of horizontal acceleration measurements in the vicinity of each of the three legs correlated with strain gage measurements on the legs and simultaneous observations of wind and wave direction and amplitude. These studies were not very successful mostly because it was very difficult to determine the true translations which involved the multiple integration of the curves obtained from rather irregular data.[17]

There is nothing mystic or mysterious about multiple integrations to determine displacements. Although done automatically by com-

[17] "Design and Construction Report," p. 64.

puters in our missile systems, it is the very same principle upon which the all-inertial guidance system works in relating the information obtained from the accelerometers.

The suspicions concerning the failure of the upper tier of bracing in the A–B plane to function properly were confirmed by diver inspection by Marine Contractors, Inc., East Boston, Mass., under Navy contract NBY–22027. In a report dated November 25, 1958, it was stated in substance that—

(*a*) The pins in the horizontal brace at −23 feet at midpoint in the A–B plane were loose (A diagonal) and withdrawn 9 inches (B diagonal).

(*b*) The Dardelet keeper plates on the B leg were loose and several of the studs and nuts were missing from them.

(*c*) None of the Dardelet bolts on either side of the collar on the A leg were in place, either having sheared off or fallen out and there was evidence of vertical motion of the collar on the caisson.

(*d*) In tightening the collar bolts to a certain torque, they would be found looser within a day or two.

(*e*) The A leg developed oil leaks which could not be repaired.

The responsibility for the failure of the Dardelet bolts on the A leg was not determinable. Although there was reason to believe that the contractor may not have installed these bolts in accordance with the plans, there was no way to demonstrate this conclusively. Conversely, it was possible that the bolts were correctly installed. As for the Dardelet bolts on the B leg, no failure was observed but roughly half were loose and all were not of design dimensions. The failure of the Dardelet bolts on the A leg permitted vertical motion of the collar on the A caisson. This movement was applying, and had applied for an unknown period of time, exceptional stresses on other bracing members, particularly in the A–B plane.

The 1st Naval District considered this failure of the Dardelet bolts a construction deficiency and required the contractor to replace them with T-bolts. Apparently, Dardelet bolts are considered by some as nothing more than a temporary device. In the fall of 1958, after confirmation of the structural deficiency in the collar connections of the upper braces on the A–B side, the design engineers issued the first in what was to become a series of warnings on the structural integrity of the tower. By letter dated September 18, 1958, Mr. Kuss wrote to the officer in charge of construction in part, as follows:

> In the meantime and if the collars cannot be tightened and the shear bolts replaced, we are compelled to warn you that a definite hazard exists to the safety of the tower and the personnel aboard in the event of a major hurricane passing directly over the tower location.

The work to replace the Dardelet bolts with T-bolts began in November 1958 but was discontinued when about 50 percent complete because of weather. None of the T-bolts were installed until the following year and the entire repair was completed in May 1959. In the meantime, with the tower in this condition, it was exposed to five severe storms with maximum waves of 33 feet in height and winds up to 90 miles per hour. The design engineers certified that upon completion of the T-bolt installation the tower would be restored to its original design strength and in a report dated June 1959, Marine Contractors,

Inc., the diver firm, certified that repairs to the collar connections were satisfactory.

The cost for replacing the Dardelet bolts with T-bolts was taken from the original "Military construction program, Texas tower" appropriation. It was said that this repair reduced the tower movement to a lesser magnitude than at any time since its construction.

In August of 1959, the 1st Naval District awarded a contract to Moran, Proctor, Mueser & Rutledge for a motion study of radome bases for towers No. 2 and No. 4. The report, dated September 16, 1959, was prepared at Air Force request to provide information as to whether or not the motion of the tower would be within the limits of acceptable tolerances for operational radar purposes. The study had nothing to do with the structural stability or instability of the tower. The completion of this report in September 1959 constituted the last item of work performed by the Navy for the Air Force in connection with Texas tower No. 4 up to the time of its collapse.

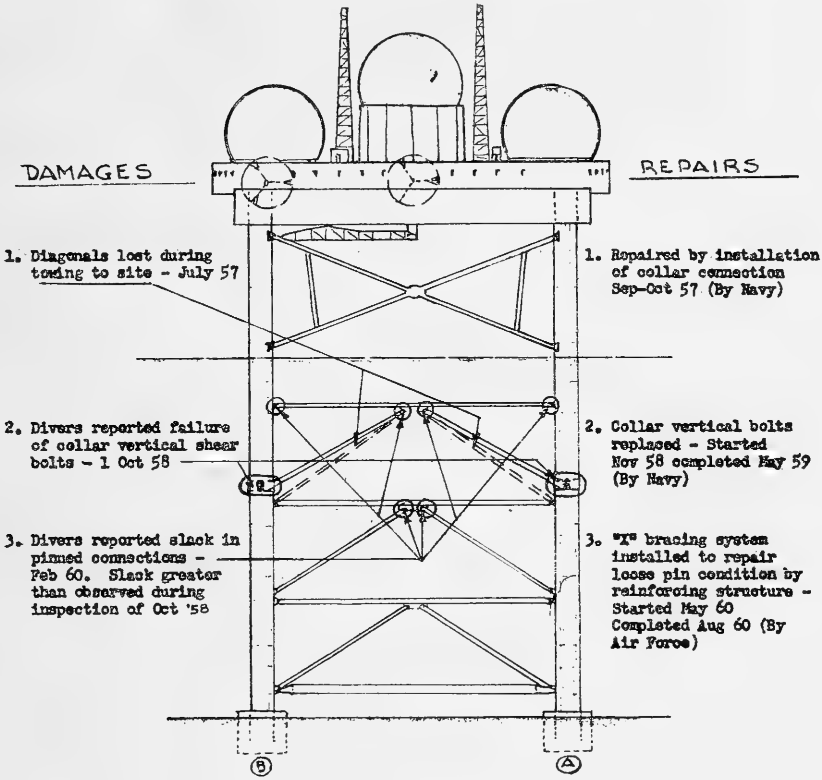
By January of 1960, less than a year after the collars were fixed, the operating personnel again complained of excessive platform motion. Marine Contractors, Inc., performed another underwater inspection in February 1960. In the report of Mr. Alan Crockett, general manager for Marine Contractors, Inc., there appears the following statement:

> This concern did a similar survey on tower No. 4 last October 1959 [sic; 1958] and the results did not show the magnitude of clearance to be found in the pins that we have appreciated during this survey. We feel that there is approximately three-fourth-inch increase in clearance between the surveys * * *. The tower movement is very erratic in an oscillatory direction * * *. The noise factor heard on the tower in the vicinity of A caisson is resulting from the motion of the tower taking up total clearances in the pins and flanges on one side or the other to bringing the two metal surfaces together at the extremity of motion causing the metallic bang.

For a more graphic illustration of the condition of the tower, there is reproduced on p. 25, a schematic diagram depicting the locations of the loose pins and worn connections.

Loose pins and worn connections became a cause for considerable concern. On March 1, 1960, the Engineering Section of the 551st Aircraft Early Warning and Control Wing at Otis Air Force Base telegraphed the 26th Air Division in Syracuse, N.Y., stating in substance that the 4604th Support Squadron had notified the 551st AEW&C wing of excessive sway in the tower on January 20, 1960; that diver inspection in early February disclosed that pins had loosened from ⅛ inch tolerance to as much as 1 inch in some cases; that this prompted a meeting with the design engineers, Moran, Proctor, Mueser & Rutledge, on February 25, who recommended the installation of abovewater bracing; that such bracing would cost from $400,000 to $500,000; and that these repairs must be accomplished on an emergency basis not later than August 1, 1960.

An information copy of this teletypewriter exchange (TWX) was mailed to the First Naval District and is more specifically identified as unclassified message No. 0979.



TEXAS TOWER Nº 4
HISTORY OF DAMAGES AND REPAIRS
2 NOV. 57 TO 12 SEP 60

The design engineers issued another warning concerning the structural integrity of the tower and the safety of personnel on board. In his letter of April 1, 1960, Mr. Kuss stated as follows:

> The loose pin connections are a very serious matter since there seems to be no way of satisfactorily remedying the condition. Furthermore, the condition is one which will tend to worsen at an increasing rate with time. This is because the looseness induces impact stresses in the pins and pin plates which are greater than for the nondynamic design assumptions and will become increasingly greater as the play in the joint enlarges.
>
> * * * We have concluded that the only practical cure for the situation is the addition of new abovewater braces which we have advocated and designed.
>
> * * * Time is of the essence in the program for erecting new braces. The hurricane season has been pretty well established as beginning after the first week of August and the schedule for construction to be reasonably sure of accomplishment should be essentially complete by that time.

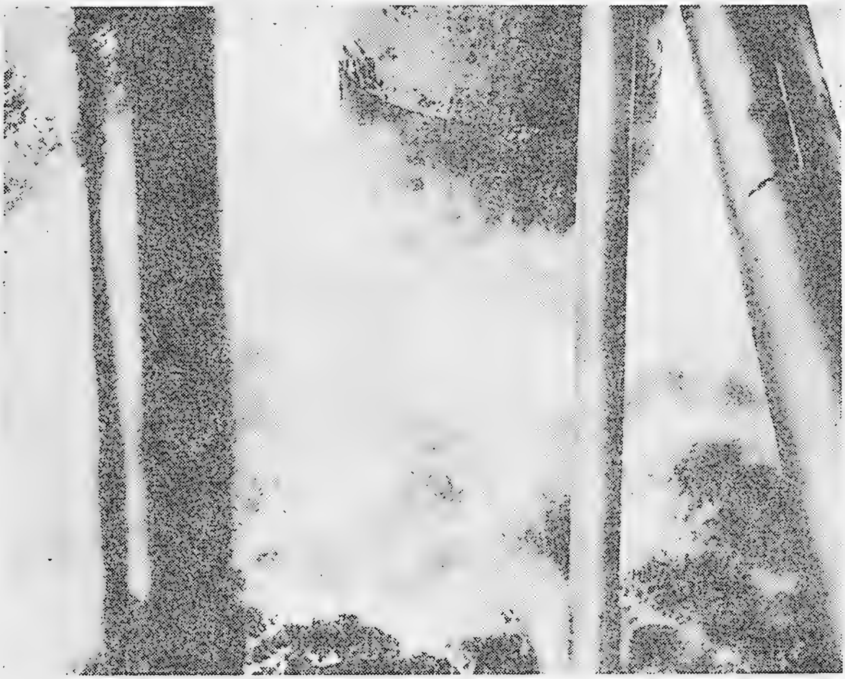
Capt. Thomas J. White (CEC), USN, the district public works officer of the First Naval District, had received a copy of the telegram from the Air Force personnel at Otis Air Force Base and had discussed with a Colonel Cipolla of the Air Force the motion difficulties being experienced at tower No. 4. The Bureau of Yards and Docks within his naval district had passed on the design and con-

struction of this tower and, although it was obviously in further difficulty of an emergency nature, he took no affirmative action to ascertain the cause of the trouble. In a letter dated March 15, 1960, to Colonel Stephany of the Air Force, he advised that he did not want the Navy to become involved in what he had orally termed nickel and dime maintenance and repair but that since "the motion difficulty appeared to be related to the original design," he would look favorably upon a request for the Navy to administer the engineering and repair contracts to correct the difficulty. In his testimony during the hearings, he stated in substance that by "original design" he also included the collar connections for the replacement diagonals.

The Air Force did not accept the offer he proferred on behalf of the Navy and dealt directly this time with the original designers, Moran, Proctor, Mueser & Rutledge and the original builder, J. Rich Steers, Inc.

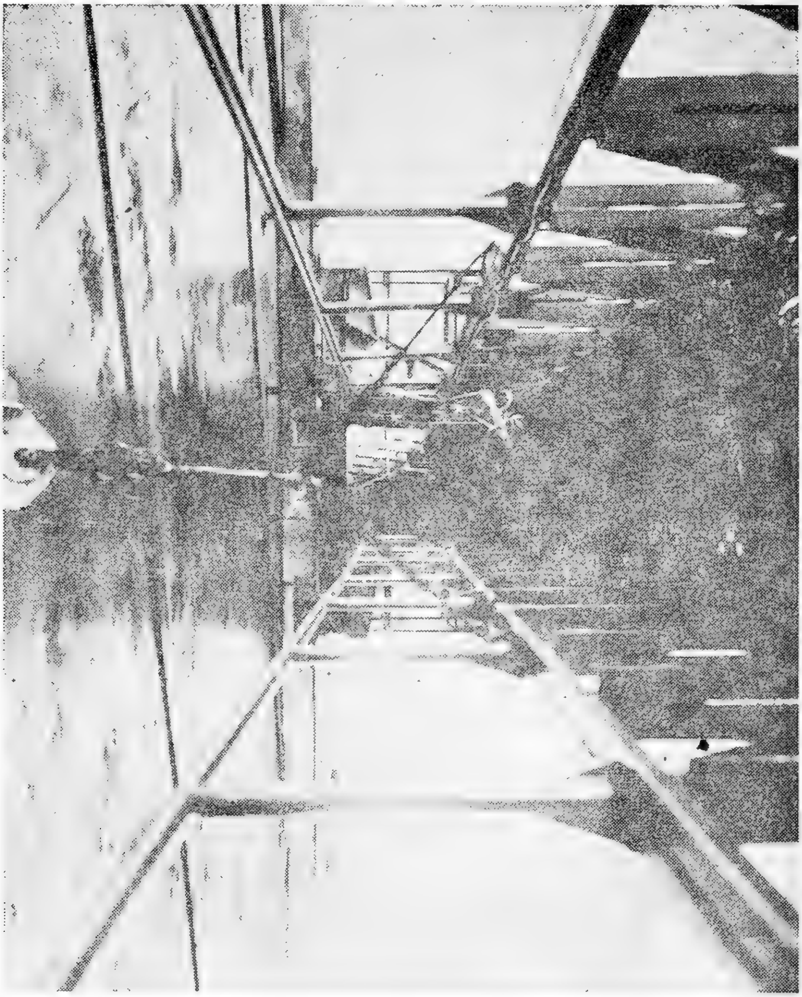
The installation of the X-bracing above water was a matter of emergency because a condition existed which would result in the probable loss of the tower if it was not corrected. This bracing was installed at elevations plus 9 feet to plus 58 feet above water in the area presenting maximum resistance to the passage of waves, and represented a scheme which was diametrically opposed to the original concept of keeping resistance to wave passage to a minimum. No effort was made to rectify the admittedly serious conditions of loose pins and worn connections underwater but, nonetheless, the design engineers on August 10, 1960, certified that the above-water X-bracing had restored the tower to its original design strength.

About a month later, on September 12, 1960, Hurricane Donna passed through the area. The actual maximum wind velocities and wave heights experienced at tower No. 4 from the effects of Hurricane Donna have not been clearly substantiated, other than admittedly having exceeded the original design criteria of 125 miles per hour for wind velocity and 35-foot breaking wave height. Some sources claim winds of 132 miles per hour and breaking waves of at least 50 feet in height. Others claim winds of 115 miles per hour velocity and breaking waves of 65 feet in height, while others claim waves of 75 feet in height, the latter purportedly being a measurement above mean sea level and not from trough to crest. Light structural steel for the exhaust vents, 8 feet above the base of the platform which was 66.5 feet above mean sea level, was dented from wave action. Shown below is a photograph of wave action against the above-water X-bracing taken at some time during Hurricane Donna.



Wave action against above-water X-bracing.

The "flying bridge" or rotating maintenance scaffold suspended beneath the tower had been torn loose and had to be repaired before divers could ascertain the damage to the underwater foundation. For graphic portrayal of damage to the "flying bridge," a photograph showing it against the C leg is reproduced.



Damage to the "Flying Bridge"

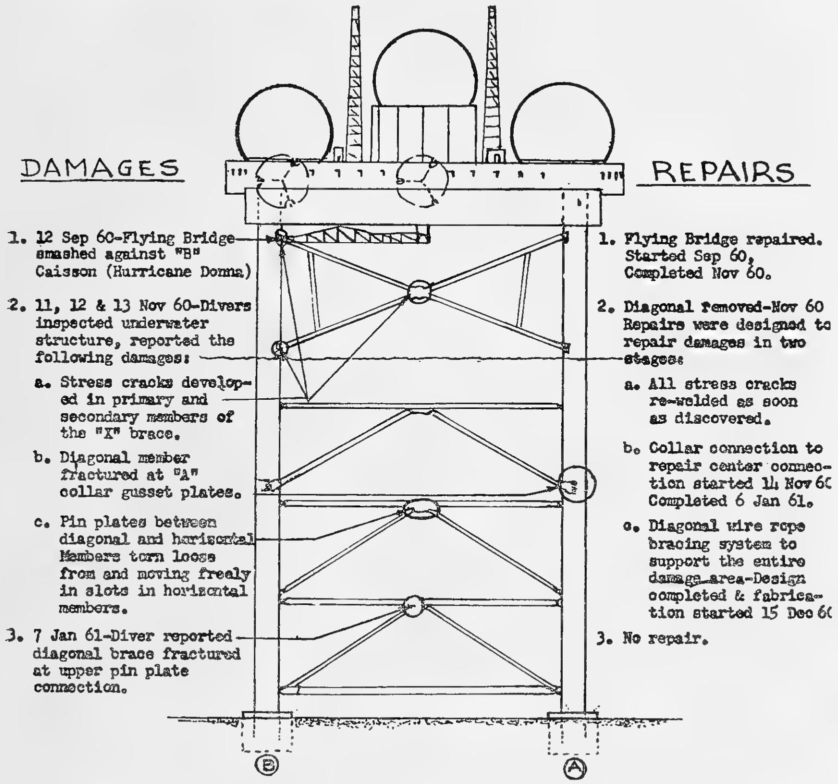
J. Rich Steers, Inc., the original builders under contract with the Air Force, completed repair to the "flying bridge" on November 1, 1960, and subsequent inspections revealed the following damage:

(*a*) The above-water X bracing was cracked and fractured in its primary and secondary members.

(*b*) The upper tier A diagonal was fractured.

(*c*) The two diagonals in the second tier of bracing at the midpoint of the horizontal at elevation −75 feet had torn loose from their attachment and were moving freely. These damages were all on the A–B side.

There is reproduced below a schematic diagram illustrating this damage with the exception that at this time the lowest diagonal brace, shown as being fractured, actually was intact.



TEXAS TOWER No. 4
HISTORY OF DAMAGES AND REPAIRS
12 SEP 60 TO 7 JAN 61

By item 4 of the contract between Steers and the Air Force of September 27, 1960, for repair of the scaffold and underwater inspection, Steers was requested to give the Air Force a report, if possible—

> concerning the tower's present structural capacity or incapacity to withstand future storm conditions within the limits set by the original design criteria of winds up to 125 miles per hour in combination with breaking wave action having a crest height of 35 feet. This statement of the present structural stability and "storm worthiness" will be of key importance to the Air Force personnel evacuation procedures for Texas tower No. 4 to prevent the loss of life in future.

At a meeting on September 28, 1960, Steers informed them that it would not attempt this work and referred the Air Force to the design engineers, Moran, Proctor, Mueser & Rutledge for such a report.

On or about October 3, 1960, the Moran, Proctor firm agreed to do this work but did not confirm it in writing until January 4, 1961. In their confirming letter, the design engineers agreed to—

(*a*) Examine the results of the findings of damage;

(*b*) Evaluate any structural deficiencies that may be found; and

(*c*) Make recommendations as to repairs or modifications to be made but the fee of $2,500 would not include the design or preparation of specifications for any new work required.

When the extent of the damage to the tower caused by Donna was reported to him on or about November 12, 1960, General Elder, commander of the Boston Air Defense Sector, became very much concerned for the reason that, throughout all the discussions over the tower's troubles, no one had undertaken to advise him of the actual remaining strength of the tower. On November 16, 1960, General Elder called Mr. Kuss by telephone, as the person probably best qualified to advise him as to the tower's remaining strength. Mr. Kuss would not do so. Whereupon General Elder ordered the evacuation of personnel from the tower to the maximum extent possible, consistent with maintaining Air Force custody of expensive and classified equipment and providing the necessary support to the construction workers. This was determined to be 14 military personnel, an insufficient number to operate the radar equipment as well, so General Elder ordered an operational standdown of the radar equipment.

General Elder also established a continuing weather watch with orders to notify him of any weather forecasts predicting wind velocities of 50 knots or more in the tower No. 4 area.

Several meetings and discussions took place between the design engineers, the contractor, and representatives of the Air Force at which the damage was reviewed and the method of repair established with an estimated completion date of April 1, 1961.

The permanent fix decided on at those meetings consisted of the installation of three strands of crossed cable bracings on the A–B side from the −125-foot level to the −25–foot level to compensate for and virtually be in substitution of the upper two tiers or panels of K braces, it being assumed that the lowest tier of bracing still possessed structural integrity. It was also decided to repair, through installation of a sleeve, the attachment of the two diagonals on the horizontal brace at the −75-foot level and this was completed on January 1, 1961, after much difficulty from winds and waves. To strengthen the legs at the lower level where the cable bracing was to be attached, concrete would be poured in, the materials for which to be delivered to the tower by the supply ship, *AKL–17*, a Military Sea Transportation Service vessel engaged solely in supplying the towers under lease to the Air Force.

On December 12, 1960, the tower was subjected to another severe storm with high seas and winds of 87 knots. Then, on January 7, 1961, the divers discovered that the B diagonal in the lowest panel of bracing was broken.

A meeting was held in Steers' office in New York City on January 12, 1961, the initial purpose of which was to negotiate costs for repair of the tower.

Mr. Rau said that the cost analysis would have to be revised because of additional work required to fix the B diagonal in the lowest panel. He said that the broken diagonal was a very grave problem and that its loss would reduce the overall structural integrity of the tower to approximately 55 percent of its original design criteria even after the

cable bracing had been installed, having learned this from Mr. Kuss by telephone earlier in the morning. Therefore, he stated, with the diagonal broken, the installation of the cross cable bracing alone would not of itself restore the integrity of the tower.

When Mr. Kuss joined the meeting in the afternoon, he stated that the tower was in critical condition with the lowest diagonal broken, and that it would require an entirely new scheme of repair and modification to bring the tower back to its original strength, at a probable cost of more than $1 million.

It was at this same meeting that Mr. Kuss was again, and repeatedly, requested to advise as to the tower's remaining strength in accordance with the responsibility his firm had assumed within the meaning of item 4 of the Steers contract with the Air Force, viz.:

> This statement of the present structural stability and "storm worthiness" will be of key importance to the Air Force personnel evacuation procedures for Texas tower No. 4 to prevent the loss of life in the future.

In response to these requests, Mr. Kuss would only say, in substance, that he, Kuss, had made an analysis on the structural integrity of the tower after the newly designed cable bracing would have been installed, and with the lowest diagonal considered ineffective; that (under this hypothetical state) the overall integrity of the structure would be 55 percent of its design strength, but that his figure could not be applied in direct proportions to the wind and to the wave criteria of the original design because these forces vary with the square of the wind velocity and only approximately with wave height.

Mr. Kuss testified before the subcommittee that a complete evaluation of the tower's strength would take about a week's time.

As a result of the meeting of January 12, 1961, it was decided to completely evacuate the tower by February 1, 1961. This was the date at which Steers would have used the grouting (sand, gravel, and cement) supplies, rewelded the X bracing above water, and this would also have allowed the Air Force time in which to winterize and preserve equipment which would be left on board pending a return in the spring to resume repair under more favorable weather conditions.

The cable bracing had not been installed.

Three days later, January 15, 1961, at 7:25 p.m., on a Sunday evening, during a winter storm, Texas tower No. 4 collapsed. There were no survivors of the 28 men on board.

The maximum prevailing weather at the time the tower disappeared, from the radar scope of the supply ship, consisted of winds of force 11 (approximately 55 knots) and waves of 35 to 40 feet in height.

6. Search and survey activities

When tower No. 4 disappeared from his radarscope, Capt. Sixto Mangual, the master of the supply ship, radioed that he had lost radar and radio contact with the tower and presumed that it had collapsed. He was ordered to confirm his message and approach the site where the tower had been.

The aircraft carrier *Wasp*, which happened to be in the area some 2 hours distant, approached the scene and assumed command of rescue operations.

One body, a military man, was retrieved from the ocean and a second body was sighted but could not be recovered. The ships in the Navy task force, along with the supply ship, were assigned search areas during which various objects (life raft, mattress, oil slicks, whaleboat) were sighted.

The sounds of tapping noises picked up by the sonar gear on one of the destroyers are now thought to have been caused by tidal currents to which the wreckage of the tower had reacted and not the tapping of survivors trapped within the tower.

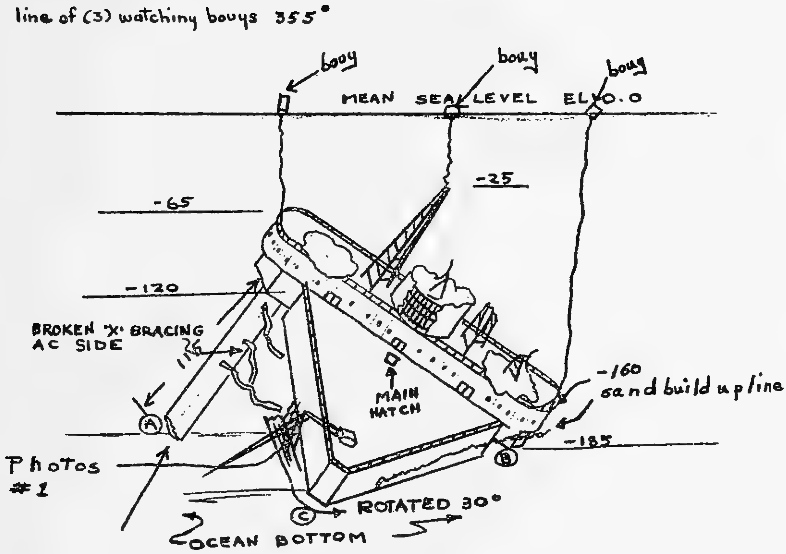
Alan Crockett of Marine Contractors, Inc., received a telephone call at his home about 4 a.m., Monday morning, asking for his services and those of his civilian divers on an emergency basis to determine whether there was any possibility of survivors. He and his men responded immediately and, despite the hazardous conditions under which they performed this work, entered virtually every compartment of the many decks and rooms of the platform. They recovered one body, a military man, in the administration area of the platform, and it was thought that he had been assigned to handle communications while the others were out on deck jettisoning the grouting material, in preparation for helicopters from the USS *Wasp* to land.

The civilian divers were joined by teams of Navy divers from the ARS *Sunbird* conducting diving inspections for about a month after the collapse to determine its present position, recover further bodies, if any, and generally survey the structure to determine the reasons for its collapse. Although Mr. Crockett requested a 30-day extension for the use of ARS *Sunbird* from which to conduct further diving operations, the vessel had a commitment in the missile program and had to be taken away from the tower No. 4 survey.

It is believed that the only means by which to ascertain the precise cause of and manner in which the tower collapsed is through an engineering analysis of the wreckage. A determination of the reasons for its collapse would have merit if the knowledge to be gained were applicable to the remaining towers. However, since they are of different design, it is doubtful if any information acquired from such an analysis would have any bearing on the integrity of towers Nos. 2 and 3.

The tower platform rests on the ocean floor 200 yards from its original location on a southwest bearing of 242°. It rotated in a counterclockwise direction through 35° so that the A–B plane is now on a bearing of N. 9° W. rather than N. 26° E.

Shown on pages 33 and 34 are two schematic views of the platform as it now rests at the bottom of the sea.

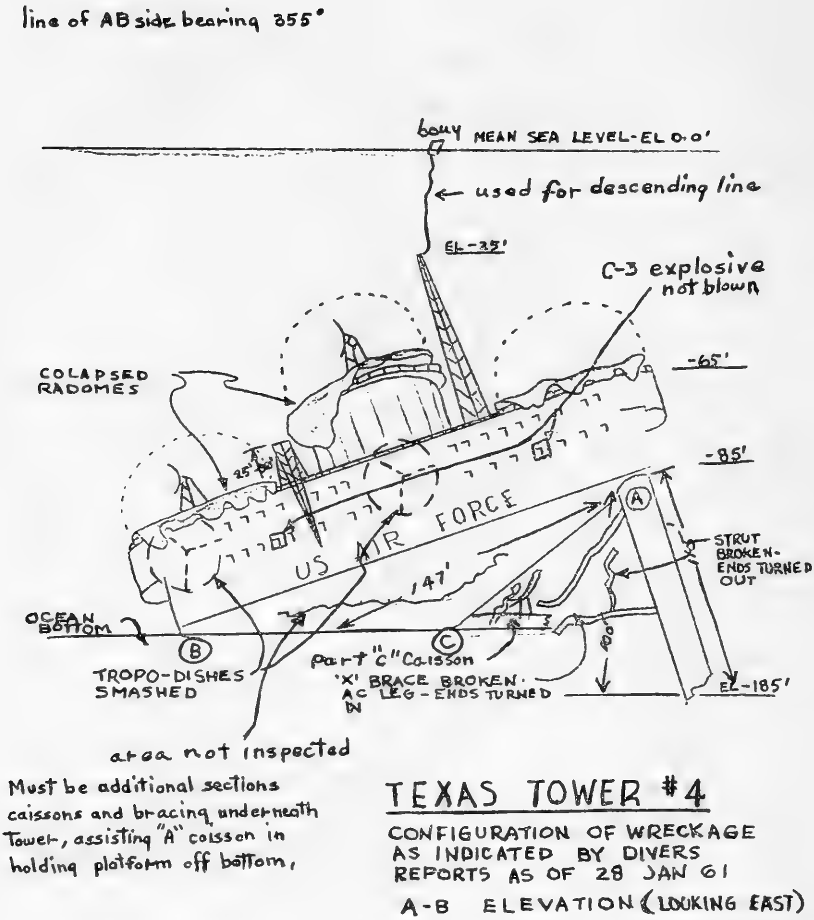


length of remaining section of A Computed to be 115'
upper deck railing carried away
all windows fractured or broken out
all hatches and doors carried away
center radome shell 50% carried away
center radar antannae down on main deck hatch
2 modulators nearly intact
BC side wire safety net carried away

TEXAS TOWER #4

CONFIGURATION OF WRECKAGE
AS INDICATED BY DIVERS
REPORTS AS OF 28 JAN 61

ISOMETRIC VIEW FROM 'C' CORNER
(LOOKING WEST)


line of AB side bearing 355°
bouy
MEAN SEA LEVEL-EL 0.0'
← used for descending line
EL-35'
C-3 explosive not blown
COLAPSED RADOMES
-65'
-85'
25'
US AIR FORCE
A
STRUT BROKEN-ENDS TURNED OUT
147'
OCEAN BOTTOM
B
C
TROPO-DISHES SMASHED
Part "C" Caisson
'X' BRACE BROKEN.
AC LEG-ENDS TURNED IN
EL-185'
area not inspected
Must be additional sections caissons and bracing underneath Tower, assisting "A" caisson in holding platform off bottom,
TEXAS TOWER #4
CONFIGURATION OF WRECKAGE AS INDICATED BY DIVERS REPORTS AS OF 28 JAN 61
A-B ELEVATION (LOOKING EAST)

The platform still has affixed to it 115 feet of the A leg, the other two legs having broken off at the base of the platform. Each of the legs fractured at their footings with the possible exception of the B leg which appears to have bent over at the footing without splitting. The footings are apparently in good condition without any evidence of fracture, movement, or scour.

Concerned over the structural integrity of and safety of personnel on board the remaining two towers which, it states, continue to be an operational requirement of the military service, the Air Force requested the Navy to take such measures as might be necessary to evaluate the safety of those towers. Pursuant to that request, Capt. Thomas J. White (CEC), USN, the district public works officer of the First Naval District, negotiated a contract with the design engineers, Moran, Proctor, Mueser & Rutledge, to perform this evaluation at an estimated cost of $225,000 to $250,000. A portion of this evaluation took the form of hindcasting the wind and wave forces actually experienced at the tower No. 4 location and extending the results of these evaluations to the maximum wind and wave conditions that should now be considered possible at the locations for towers Nos. 2 and 3.

Captain White maintained that the obligation of the design engineers under this contract is merely to determine whether the two remaining towers were constructed in accordance with the design. On the other hand, in view of the fact that the design criteria for tower No. 4 proved to be inadequate, that the tower had taken the lives of 28 persons, and that many more lives were at stake on towers Nos. 2 and 3, the reason for conducting the evaluation is to determine whether the men on board are safe and not merely to determine whether the construction of the towers was in accordance with a design criteria which had proved to be inadequate.

FINDINGS AND CONCLUSIONS

Based upon its investigation and the testimony elicited from open hearings held on the collapse of Texas tower No. 4, the subcommittee makes the following findings and conclusions:

I

Finding.—The Navy's Bureau of Yards and Docks, at the request of the Air Force, agreed to act as its design and construction agency in the implementation of the Texas-tower concept.

Committee conclusion.—A substantial portion of the responsibility for the defects, deficiencies, and inadequacies in the design and construction, and in some cases in the repair, of Texas tower No. 4 rests squarely upon the Bureau of Yards and Docks of the Department of the Navy.

II

Finding.—Texas tower No. 4 was designed to withstand winds of 125 miles per hour in combination with breaking waves of 35 feet in height measured from trough to crest. This criteria was unquestionably exceeded during Hurricane Donna in September 1960, when winds of 132 miles per hour and breaking waves of at least 50 feet in height were experienced. It had also been exceeded by recorded or reliably

computed wind velocities and wave heights during the 20 years immediately preceding the tower's erection, although not necessarily in combination.

Committee conclusion.—The design criteria was clearly inadequate. Those charged with the responsibility for its determination, the Navy's Bureau of Yards and Docks and the structural design engineers—the firm of Moran, Proctor, Mueser & Rutledge—underestimated the environmental wind and wave forces to which the tower would be exposed during its anticipated 20-year life in the Atlantic Ocean. The forces of wind and wave which exceeded this criteria should have reasonably been foreseen on the basis of the findings from the feasibility study conducted by the structural design engineers and approved by the Navy. The structural design engineers miscalculated in believing that the design criteria was reasonable and safe.

III

Finding.—The patented Kuss tip-up method, by which the template, consisting of the legs and their bracings, was fabricated in port, floated to the site in a horizontal position, and upended to a vertical position was utilized in the erection of Texas tower No. 4. This was the first time the method had been used in erecting an offshore structure and it has been used only once since that time. The inventor, Mr. Kuss, became an employee of the structural design engineering firm shortly after the design contract was awarded to that firm.

Committee conclusion.—The subcommittee seriously questions the wisdom of using for the first time, on a structure such as tower No. 4, an untried, untested process which had not even been considered as a method of erection by the Navy's Bureau of Yards and Docks until after the inventor thereof was employed by the structural design engineering firm.

IV

Finding.—Several changes which deviated from the design specifications were recommended by the contractor, J. Rich Steers, Inc.-Morrison-Knudsen Co., and approved by the structural design engineers. One consisted of an increase in the tolerances between the pins and the connections into which they were inserted for connecting the braces. Another change permitted the substitution of the permanent platform for the originally intended temporary one. This change had two major consequences in that it meant that the heavier permanent platform would be raised on legs which had neither been embedded nor stiffened or reinforced with concrete and that the upper panels of diagonal bracing had to be folded down and secured to the horizontal braces of the next lower panels. The structural design engineers first approved and later disapproved the method proposed by the contractor in lashing down the diagonal struts. Prior to tip-up, two of these diagonal braces were damaged and lost.

Committee conclusion.—

1. The damage and loss of these braces resulted either from a deficiency in the designed method of erection as changed, from an inadequate or insecure lashing down of the braces, or from exceptional stresses in upending the template in position. The structural design engineers miscalculated the effect of the seas during the tow and tip-up

of the template in requiring an alternate method of lashing down the braces.

2. The damage to and ultimate loss of the diagonal braces in the upper panel on the A–B side constituted a major and serious structural break or mishap.

3. While there is a conflict of engineering opinion on the use of pin connections as opposed to welded connections for a structure subjected to the continuous unrelenting random forces of the sea, if pins were to be used, the subcommittee does not believe that increases in tolerances above those called for in the original specifications should have been permitted.

4. The increased tolerances in the pin connections permitted movement of the tower in reacting to the forces of the seas. The movement of the tower in turn caused an aggravation and deterioration in those pin tolerances to the point where their looseness and wearing reached alarming proportions.

V

Finding.—When the loss of the two diagonal braces was discovered, the alternatives were to return the template to port for repair or to proceed with the erection of the tower and attempt repairs at sea. The naval officer in charge of construction declined to assume responsibility for the decision and asserted that the contractor had sole authority for the decision. Conversely, the contractor denied making the decision and testified that the responsibility for the decision had to rest with the Navy. The structural design engineers disclaimed any responsibility for the decision. However, all parties concerned agreed that the other party's decision was correct in attempting repairs at sea.

Committee conclusion.—

1. The Navy cannot escape or avoid responsibility for this decision as the naval officer in charge of construction was vested with the power and authority to direct the contractor to return the template to port for repair.

2. The decision to remain at sea and attempt underwater repair of the braces was, in the opinion of the subcommittee, the point of no return and the time at which the fate of the tower was sealed.

VI

Finding.—The attempted replacement at sea of the lost braces, in accordance with the method designed by the structural design engineers, was handicapped by the motion of the tower and the inherent restrictions of underwater repair work of such magnitude. This repair, a collar attachment secured by Dardelet bolts, completed by November 1957, failed to hold and the deficiency was not corrected until T-bolts were installed in May 1959. In the fall of 1958, the structural design engineers issued their first warning that a definite hazard existed to the safety of the tower and the personnel aboard.

Committee conclusion.—

1. The initial deficiency occurring in July 1957 in the upper tier of bracing on the A–B side, although modified in November 1957 and corrected by May 1959, was the first indication of structural weakness in

the tower. It was the source of structural deterioration from which further numerous defiicencies developed. Repairs could not keep ahead of the progressive structural deterioration and developing deficiencies. The culmination of these deficiencies weakened the tower to the point of collapse.

2. The structural design engineers in the redesign of the collar attachments by November 1957, as a fix for the diagonal struts lost prior to the tip-up of the template, placed too much reliance upon underwater diver-repairmen working under adverse conditions.

3. When the tower was accepted from the contractor by the Navy and at the time the Navy turned it over to the Air Force in November 1957, the tower possessed an unknown structural deficiency in the failure of the Dardelet bolts of the collar connections and was in a weakened condition.

4. Before the deficiency in the collar connections was discovered in the fall of 1958, and corrected in May 1959, the tower, in its weakened condition, was exposed to the effects of storms of two winters resulting in exceptional dynamic impact stress concentrations on other foundation connections.

VII

Findings.—The design configuration of the tower in the use of three legs of minimum diameter with no auxiliary legs was based on the concept of keeping the resistance to wave passage to a minimum. In early 1960, a diver inspection revealed that there were loose pins and worn connections in the upper two panels of braces on the A–B side, a condition which necessitated emergency repairs prior to the 1960 hurricane season. The structural design engineers issued a second warning of the hazardous condition and probable loss of the tower and advocated the installation of above-water X bracing. Upon its completion, the structural design engineers certified on August 10, 1960, that the tower had been restored to its original design strength. No attempt was made to repair the loose pins and worn connections in the underwater braces.

Committee conclusion.—

1. The X bracing above water, aside from materially increasing the stresses exerted against the tower, was contrary to and militated against the original design concept in keeping resistance to wave passage to a minimum and, in fact, these braces were placed in an area where the force of the passing waves was greatest.

2. The subcommittee cannot understand how the tower could be certified as having been restored to its original design strength merely upon the installation of the X bracing in the absence of the repair of the worn pin connections underwater.

VIII

Finding.—Additional and serious damage was inflicted on the tower by Hurricane Donna in September 1960, at which time the design criteria was admittedly exceeded. The original builder immediately began inspection and repair of the tower. On October 3, 1960, the structural design engineers, under subcontract with the original builder, agreed to evaluate the remaining strength of the tower in

terms of wind velocities and wave heights, a computation which requires roughly a week's time. In the middle of November 1960, after the extent of the damage caused by Hurricane Donna became known and after one of the structural design engineers, Mr. Kuss, declined to advise as to the tower's remaining strength, General Elder, commander of the Boston Air Defense Sector, ordered an evacuation of personnel from the tower to the maximum extent possible consistent with maintaining military custody of valuable Air Force equipment and with providing support to the civilian workers engaged in further tower repair.

Committee conclusion.—Were it not for the commendable exercise of prudent judgment demonstrated by General Elder in ordering maximum possible evacuation of personnel and operational standdown of tower No. 4 because the structural design engineer would give him no indication of the tower's residual strength, it is probable that a far greater number of lives would have been lost.

IX

Finding.—It was proposed that cable bracing in a crossed pattern on the A–B side of the tower would be installed to substitute for and be in lieu of the upper two panels of braces on the assumption that the lowest panel of braces on that side was still intact and functioning properly. Work preparatory to the installation of this cable bracing was in process but these braces had not been installed prior to the tower's collapse. A storm occurred on December 12, 1960, after which it was discovered that a diagonal brace in the lowest panel was broken. This defect was discovered on January 7, 1961. On January 12, 1961, the structural design engineers were again requested to advise as to the remaining strength of the tower, but would not do so other than to state that it was in a dangerous condition. It was further stated, in what appears to have been somewhat of an off-the-cuff opinion, that even after the cable bracing had been installed, but with the lowest diagonal brace still broken, the tower would then be only 55 percent as strong as its original design strength, but that the percentage could not be applied in direct proportion to wind velocities and wave heights of the design criteria.

Committee conclusion.—From September 12, 1960, to the date of the tower's collapse on January 15, 1961, the structural design engineers either could not or would not evaluate the tower's remaining strength even though it could have been done in a week's time; despite the fact that they were under a contractual responsibility to evaluate the tower's residual strength; and in the face of the obvious and urgent need of the Air Force to possess such an evaluation.

The neglect or failure of the structural design engineers to evaluate the tower's remaining strength afforded no measure by which the Air Force could relate its predicted weather forecasts to the wind and wave forces the tower was capable of withstanding at the time of its collapse.

X

Finding.—The Air Force, as the using agency, operated and maintained the tower over a period of several years during which time it had actual knowledge and continued notice and warning of the dangers and hazards inherent in the structure. From August 10, 1960, the date at which the tower had last been certified as being up to design strength, to the date of its collapse on January 15, 1961, the Air Force was given information on the nature and extent of the tower's damage.

Committee conclusions.—The Air Force is chargeable with the responsibility for the safety and well-being of the personnel on board the tower, both civilian and military, and must accept a substantial portion of the blame for the loss of the 28 persons on board at the time of collapse in failing to order a timely evacuation of the tower.

It was apparent from September 12, 1960, the date at which Hurricane Donna caused such serious damage, to January 15, 1961, a period of 4 months, that the tower was greatly weakened; that it was in a dangerous condition and that it was highly unsafe. The winter storm season was in progress and it was known that it would continue for several months more. A complete evaluation of the tower should have been made and all personnel evacuated or, as a minimum alternative, highly effective measures taken which would insure safe and timely evacuation of all personnel in advance of any predicted storms.

XI

Finding.—The Air Force, concerned over the safety of the personnel still on board the remaining two towers, immediately after the collapse of tower No. 4 requested the Navy to take necessary action to evaluate the safety and integrity of towers Nos. 2 and 3. Pursuant to the Air Force request, the Navy, on January 24, 1961, awarded a negotiated contract to the structural design engineers to perform this evaluation at an estimated cost of $225,000 to $250,000. Towers Nos. 2 and 3 are still in the process of being evaluated. No report has yet been prepared, therefore no finding has been made by the structural design engineers that these two towers are safe.

Committee conclusion.—The action of the Navy in awarding a contract to the structural design engineers to evaluate the safety of structures which they themselves had designed and particularly in view of the many structural failures and ultimate collapse of tower No. 4, also of their design, constituted a grave and serious error of judgment.

The subcommittee can only conclude that it would have been not only preferable but virtually mandatory under the circumstances that such an evaluation be performed by independent experts who took no part in either the design, construction, or repair of any of the Texas towers.

XII

Finding.—The Air Force does not propose to replace tower No. 4 and has informed the subcommittee that the continued operation of towers Nos. 2 and 3 remains an operational requirement in our national defense radar system.

Committee conclusion.—The decision not to replace tower No. 4 with a structure performing a like function raises serious doubt as to whether tower No. 4 was indeed an operational requirement of the service at the time of its collapse.

The continued need for maintaining the operation of towers Nos. 2 and 3 is a decision calling for the exercise of military judgment, a decision over which the subcommittee is not superimposing its own judgment.

O